XII. *Researches in Spectrum-Analysis in connexion with the Spectrum of the Sun.—* No. V.

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[Plate 67.]

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I. INTRODUCTION.

It has long been clear that the means placed at our disposal by photography for studying the solar spectrum enable us to construct maps of the region more refrangible than *b* on a much larger scale than those hitherto employed.

At the same time, as our knowledge of the molecular conditions under which changes in spectra occur is increased, it becomes necessary to embrace more and more detail in the inquiry.

Hence in former communications to the Royal Society I have pointed out that in order to increase our knowledge of the sun's chemical constitution, and to have a ready and unfailing means of detecting cyclical changes, maps of the spectrum on a large scale must be constructed.

By means of the photographic method described in the third Memoir of this series,[*] and illustrated by its application to the mapping of the spectra of barium, calcium and strontium in the fourth,[†] I commenced in the year 1875 a new map of the solar spectrum on four times the scale of ÅNGSTRÖM'S "Spectre Normal." Specimens of this map in its earlier stages were laid before the Society, with a preliminary note, in November of that year.[‡] After the presentation of this preliminary note, the construction of the map was carried on, until on January 10, 1877, I submitted to the Royal Society a complete Memoir on the first part completed (W.L. 390–400 millionths millim.) with comparisons of the lines of 25 metals and complete tables, both of the solar and metallic lines.

While this Memoir was in the hands of the referees, I received from my friend Mr. L. M. RUTHERFURD, of New York, a magnificent reflection grating, with 17,280 lines to the inch. This enabled me to attack the question of wave-lengths in a much more satisfactory manner than I had been able to do in the first instance. I therefore determined to reject my two years' work and to do it all over again, in order, if possible, to introduce greater accuracy than the method of graphical interpolation, which I had been compelled to adopt in the first instance, had permitted. I therefore applied to the Royal Society for leave to withdraw my paper, giving the above-stated reason for so doing, and at once received the required permission.

I now beg to re-submit to the Society that part of the withdrawn Memoir which has reference to the spectrum of the sun, independently of the spectra of the metals. I have determined to do this, not only because the reviewing of the wave-lengths of the metallic lines will take considerable time, but because during the time that the Memoir was in the hands of the Royal Society, and that which has elapsed since I received it back, I have very nearly completed the survey of the whole of the metals for this region, so that the comparison can now shortly be given for the whole of the metallic elements united for this part.

The section of the new normal spectrum comprises, as I have said, the FRAUNHOFER lines between W.L. 390-400 millionths millim. That portion of the map now in question is but a very small fraction of the whole region of the spectrum workable by photography, and my chief object in thus forwarding a fragment to the Royal Society is to point out the necessity for, and to invite co-operation in, a work of such magnitude, and to publish full details of the methods I have found most effective for the use of those who may take up the research. For this reason, and because it may happen that a diffraction grating of the requisite brilliancy may not be forthcoming in all cases, I think it best to give a complete history of the production of the map, including that stage of graphical interpolation of wave-lengths which I have, by Mr. RUTHERFURD'S generosity, been able to supersede.

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[*] Phil. Trans., Vol. 164, Part II., p. 479.

[†] Phil. Trans., Vol. 164, Part II., p. 805.

[‡] Proc. Roy. Soc., 158, 1875.

II. REFRACTION MAP.

A. Instruments, &c.

The same general arrangement of the spectroscope, electric lamp, and lenses figured in the third of the present series of memoirs has been employed for obtaining the photographs used in the construction of the refraction map.

The spectroscope used is one constructed on the model of Bunsen and Kirchhoff, by Schmidt and Hensch, of Berlin. It is provided with a train of four flint glass prisms, viz., three of 45° and one of 60°.

The prisms are levelled by Kirchhoff's method, and adjusted as nearly as possible for the minimum deviation of the centre of the section being worked upon.

The camera employed is provided with a simple quartz lens of 5-feet focus. The image of the spectrum formed by this lens falls on a sensitized glass plate, 16·6 × 5·8 centims. The dispersion obtained by this arrangement gives a photographic impression, in which the distance from G to K (using Cornu's nomenclature) is about 11 centims. and from H to K about 1·3 centims.

The focus is first fixed approximately by viewing the image of the spectrum on the ground glass focussing screen by means of a positive eye piece, and the final adjustment is determined by a series of trial plates, using the solar spectrum when possible, or, in the absence of the sun, the spectrum of some metal such as cerium, which contains an immense number of lines throughout its entire length. For fine definition it is requisite that if the beam of light which falls on the slit is not parallel, the light of the wave-length to be photographed should be brought to focus on it.

B. Method of Mapping.

a. *Construction of Interpolation Curves.*

The relative positions of all the most prominent lines visible in an enlargement of the photographs employed were first laid down on a strip of paper and then transferred to the horizontal line ruled at the base of some curve paper to furnish the ordinates. The lines thus selected were referred to Cornu's map, and their wave-lengths furnished the abscissæ. A wave-length scale was marked off on the vertical line, 4 millims. of which represented 1 millim. of Cornu's map. In the case of lines assigned to particular metals by former observers, a photograph of the metallic and solar spectra confronted was found useful in this work of identification. The wave-lengths of the selected lines having been found, vertical lines are carried up from them, and horizontal lines marked across from the corresponding wave-lengths. Where the vertical and horizontal lines meet, a series of points is obtained, through which is drawn a curve with as much regularity as possible. The drawing of this curve at once reveals errors of identification or of wave-length in the map used.

Two curves (A and B) were employed in the construction of this section. The first curve (A) was obtained from an enlargement on glass, and was available from about W.L. 386·0 to 399·98 millionths millim. The distance between K and H in this photograph is 3·5 centims., and it was employed in preference to RUTHERFURD'S print, because being in much better focus it was more easy, in consequence, to compare it with CORNU'S map.

The second curve (B) was constructed from RUTHERFURD'S print, commencing at the point where the photograph referred to in the last paragraph fails; this curve extends from W.L. 397·045 to W.L. 400·925 millionths millim.

The wave-lengths are expressed in x^{th} metres, and are given in two places of decimals. This has been found necessary in order to distinguish between lines very close together. The greatest error in the method of determining wave-lengths by graphical interpolation does not much exceed 2 millims. of the present scale $=\frac{1}{2}$ millim. CORNU'S scale $=\frac{1}{20,000,000}$ millim. in the actual wave-length.

I have not thought it necessary to reproduce the curves, but at the end of the paper I give two tables which will show the accuracy which it is possible to secure by the method above described. The experience gained in constructing these curves (I had already completed the region W.L. 390–440 millionths millim. before I received the grating, of which mention has already been made, from Mr. RUTHERFURD) leads to the following conclusions:—

I. The photograph of the solar spectrum employed should be on as large a scale as possible.
II. The wave-length scale giving the abscissæ should never be smaller than that used here.
III. The photograph should be tested for distortion after enlargement.
IV. The fundamental lines should be copied from the glass and not from an enlargement on paper.

β. *Construction of the Map.*

The photograph used for the construction of the original refraction map is the original negative varnished and examined by a lens, or placed under a simple microscope of low magnifying power. Considerable loss of detail and sharpness, leading to the obliteration of faint lines and the fusion together of close groups, has been found to be an invariable effect of photographic enlargements. Thus in section W.L. 390–400 millionths millim., there were mapped 333 lines in the refraction map as completed, whereas in the map of the same section exhibited to the Society in November, 1875, which was drawn from an enlargement, there were but 221 lines. I may add that the same holds good with metallic spectra. Thus the spectrum of cerium as first mapped from enlargements contained several broad and nebulous bands which the negatives now in use resolve into groups of distinct but closely-packed lines.

The drawing of section W.L. 390–400 millionths millim., exhibited with the preliminary note before referred to, was utilised for the first revision of the refraction map, for which purpose it was sufficiently good, although not good enough for copying finally, having been produced, as before mentioned, from a photographic enlargement of this region of the spectrum.

The method adopted in drawing the final refraction map was the following. A millimetre scale of the required length having been drawn near the top of a sheet of paper prepared for the reception of the map, the fundamental lines were first entered in their correct positions in pencil upon it, and afterwards made of their correct widths and intensities, as seen in the standard photograph, by means of a drawing pen and Indian ink. The width of these fundamental lines, where sufficiently great, was found by actual measurements on the curve. The spaces between these fundamental lines being too large on the scale adopted for interpolating the intermediate lines accurately by eye, their places in the photograph were found and their corresponding wave-lengths determined by means of the curve.

The lines obtained in this manner by the aid of the interpolation curves were entered in the map in the same manner as before.

A skeleton map is thus obtained, in which no greater extent is left blank than 8 or 10 millims.—a distance sufficiently small, considering the shape of the curve, to allow of the interpolation of the intermediate lines by eye. The standard photograph, placed under a microscope of low magnifying power, was accordingly made to furnish the details for the remaining lines, which were interpolated with the greatest possible care, the interpolation position being checked from time to time by actual measurements of the wave-lengths of the selected lines on the curve.

In all cases the agreement was as close as could be desired.

In order to save the cost of engraving, a third map was constructed from the finally revised copy on twelve times the scale of ÅNGSTRÖM'S. This enlarged map was photographed down to the original scale adopted for this work, viz., four times the scale of ÅNGSTRÖM. For this enlarged map I was greatly indebted to Lance-Corporal MURRAY, R.E., who made the drawing with great skill and care.

γ. *Determination of the Wave-lengths of the Solar Lines.*

I have no means for determining wave-lengths absolutely, but the accurate measurement of the wave-length of the chief lines in the ultra-violet portion of the solar spectrum by CORNU rendered it unnecessary to attempt any absolute measurements for the construction of the present map. The last degree of accuracy in the determination of wave-lengths is also, I think, having regard to the objects I have had in view, of less importance than good maps showing the details of the spectrum. The idea was at first entertained of simply copying CORNU'S map on the scale now adopted, and interpolating new lines by eye; but for two reasons this idea had to be abandoned.

In the first place, CORNU's map, although by far the best ever published of this region of the spectrum, was found to be considerably wanting in detail when compared with the best negatives taken with the camera before described. For example, the following lines are represented as single in CORNU's map :—

Section 3900–4000.

Approximate wave-length.	State in new map.
3920·4	Double.
3920·8	”
3921·3	Triple.
3935·2	Double.
3937·8	”
3952·0	Triple.
3965·0	Double.
3965·9	”
3993·3	”
3993·9	”
3997·3	”

In the next place, on the increased scale of the new map, the omission of lines by CORNU gives rise to blank spaces of too great an extent to enable one to interpolate new lines by eye with sufficient accuracy.

CORNU admits that he has attempted to give groups of lines a natural appearance (when contrasted with photography), without special reference to the position of lines within the groups. Slight errors thus introduced, although unimportant on ÅNGSTRÖM's scale, would be considerably exaggerated on the scale now adopted.

The table of wave-lengths of the refraction map depends then (1) upon CORNU's values as far as they are available, and (2) upon the interpolation curves for all the other lines. I have already stated the degree of accuracy which they may be expected to possess.

III. DIFFRACTION MAP.

A. INSTRUMENTS, &C.

The stand and collimator of the spectroscope of the BUNSEN and KIRCHHOFF model already referred to were utilised, the train of prisms being removed and replaced by the grating. This grating, which as I have already said I owe to the great kindness of Mr. RUTHERFURD, contains 13,321 lines 25 millims. long (17,280 to the inch). The ruled portion occupies the centre of a plate of glass 40 millims. square ; a deposit of silver is made on the ruled side, and then another plate is cemented with Canada balsam to the silvered side, to protect the surface. The grating is mounted with wood at the back, over the centre of a brass circular plate free to move on another lower plate levelled by screws.

The observing telescope, after a few preliminary observations to adjust the grating for verticality, was replaced by the long camera before mentioned.

The focus for any one order was determined in much the same way as in the case of the refraction photograph; that is, it was first roughly obtained by viewing the spectrum on the ground glass screen by means of a fixed positive eye piece, but the final adjustment was likewise determined by a series of trial plates, and, when satisfactory, the sliding end of the camera was clamped up tight in order to keep the adjustment as rigid as possible.

The spectrum of the second order was first obtained.

In this the distance between the H and K lines was nearly 8 millims.

With the angle between the collimator and the camera which I used, the H and K lines of the third order are brought to focus with the D lines of the second order, so that practically the grating and instruments generally are in the first instance adjusted for D, with the exception that the violet light is focussed on to the slit.

In the photograph thus obtained the H and K lines are about 15 millims. apart, and the perfection of the grating is demonstrated by the definition of the photographs, except in those parts of them where, in consequence of the presence of the glass plate, the purity of the spectrum is marred by interference effects.*

As the exposure for the third order spectrum was much longer than that required by the train of prisms, the photographs used were taken by means of a siderostat, the use of which gives great constancy to the direction of the beam of light employed. At times, an opera glass was used for obtaining a parallel beam; at others, the centre of the beam (of 12 inches diameter) thrown by the siderostat was grasped by an 8-inch object glass, and focussed on the slit.

B. Determination of Wave-lengths.

The small original negative was enlarged by many stages to obviate all chances of distortion, until a glass positive was obtained of sufficient size to commence operations upon. This was 24 centims. in length. The wave-lengths of the extreme points having been taken from Cornu's map, it was divided into ten parts carefully by compasses. It was then found that the intermediate wave-lengths did not correspond with those of Cornu. I at first feared that some distortion had, after all, been introduced; and to test this I employed a photograph on which wave-lengths 38 and 40 were taken as extreme points, and the distance between them divided into twenty portions in like manner. I then found that, although the point 39 was very slightly changed, all the rest of Cornu's measurements between 39–40 fitted the photograph very well. That is, I found that the ten points between 39, as thus determined, and

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* Mr. Rutherfurd, who has carefully studied these phenomena, ascribes them to the so-called "Talbot Bands."

40 fell as near the places assigned by CORNU as could possibly be expected, considering the great difference in the scale employed, and the vast increase in the details obtained by the grating. The new place for 39, which lies at 38·992 on CORNU'S map, was finally settled as the start-point. The distance from 39 to 40 on the glass plate was carefully divided into 1000 parts; a scale was made in ink, and from the glass plate, which now contained both the spectrum and the scale, an enlargement on paper was obtained slightly greater than the map to be produced from it.

I willingly here express my great obligation to M. CORNU'S work, and add a tribute of admiration to its value and completeness. The way in which it bears the severe test put on it by the larger scale I have employed is marvellous.

C. CONSTRUCTION OF THE MAP.

Being thus in possession of an enlarged photographic print on which are marked the absolute wave-lengths, the next thing done was to study it side by side with a refraction photograph brought up to the same scale. Owing to the cause I have before referred to, it was found that, though there was no difficulty in recognising the chief lines in both, still in the diffraction photograph the smaller details were in many places quite different, and in many others very difficult to harmonise, the intensities of the lines having been greatly changed. Although, therefore, I was able to use the diffraction photograph for the positions of the chief lines, I had to depend on the refraction photograph for the detailed work and the intensity of the lines.

A trial map on the scale adopted was then very carefully made by the aid of the photographs and the original standard refraction negative. An enlargement was then made on three times the scale, =twelve times the scale of ÅNGSTRÖM.

I tried several methods of conveniently comparing the drawing with the photograph, after the chief lines had been inserted in positions indicated on the scaled negative. The following I found most satisfactory, and, indeed, it has been of great service in the construction of the map.

The board on which the large-scale map was drawn was placed in an upright position, and at about 10 feet in front of it a small sighting aperture of 3 millims. diameter was adjusted.

The diffraction photograph with its accompanying scale was supported between the board and this aperture, care being taken to keep the line joining the eye-hole and the centre of the map at right angles to the plane of the map, and the plane of the photograph parallel to the same plane. The position of the photograph was so adjusted that the lines on the photograph and the map, thus viewed from the observing aperture, were absolutely continuous. In this manner I was able to correct any error in the positions of the lines in the enlarged map with the greatest certainty. The details and intensities were added afterwards by mounting the refraction photograph in the same manner. Having thus corrected, checked, and finished the large map in ink, it was sent to the School of Military Engineering at Chatham, where, by the kind permission of the authorities, it was photographed down to the scale determined upon.

IV. IMPORTANCE OF THE PHOTOGRAPHIC METHOD.

The importance of applying photography to the violet and ultra-violet portions of the solar spectrum seems to have been fully appreciated by ÅNGSTRÖM.*

The classical "Spectre Normal" is avowedly incomplete about this region, both with regard to the number of lines and their wave-lengths. Even in portions of the spectrum distinctly visible—such, for example, as from G to F—a good photograph shows a much greater number of lines than the corresponding region of the "Spectre Normal." Similarly with regard to metallic spectra: the most complete spectral maps hitherto published, those of THALÈN,† contain in a given region a much smaller number of lines than are mapped for the same region by means of photography, even when the spectra are purified to the greatest possible extent by the elimination of all known impurity lines. Numerical comparisons illustrating this superiority of the photographic method over eye observation have already been given in the preliminary note before referred to.

Since the publication of the "Spectre Normal," and of ÅNGSTRÖM and THALÈN'S map of the violet portion of the solar spectrum, a map of the ultra-violet region has been constructed by MASCART‡ by means of photography; but this map possesses the disadvantage of an arbitrary scale, and no metallic lines are introduced. A diffraction spectrum obtained by means of photography was published by Dr. DRAPER in 1872. This spectrum extends from beyond G to O, and although the best diffraction spectrum hitherto published, the wave-length scale is too indistinct and blurred for use in very accurate measurements. The allocation of the lines with those of metallic spectra is, moreover, not shown, although the author states that he has photographed some of the metallic spectra, both by means of a grating and of a train of quartz prisms. The excellent photograph of the solar spectrum taken by Mr. RUTHERFURD, as might have been expected, contains a much greater number of lines than the "Spectre Normal" for the same region, but being a refraction spectrum is of course not available for the purpose of directly determining wave-lengths. The most perfect map of the violet and ultra-violet solar spectrum at present in existence is that recently published by CORNU, who has determined absolutely the wave-lengths of thirty-six of the principal lines in the portion of the spectrum included between O (wave-length 3440) and beyond *h* (wave-length 4120), the remaining lines, about 650 in number, being introduced by interpolation. This map was constructed by means

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[*] "Quant à la lumière violette et extra-violette, j'espere pouvoir, à l'aide de la photographie, en publier bientôt un aperçu exact et détaillé, surtout comme les tentatives, déjà faites à cet égard par M. THALÈN, confirment ces espérances."—('Recherches sur le Spectre Solaire,' Upsal., 1869.)

[†] 'Nova Acta Regiæ Societatis Scientiarum.' Upsaliensis, 1868.

[‡] "On the Rays of the Ultra-violet Solar Spectrum." 'Compt. Rendus,' Nov., 1863.

of photography, and although very incomplete so far as regards metallic coincidences, it has proved of invaluable service in the construction of the present map.

That the value of the photographic method has not been over-estimated will be rendered evident from the following considerations.

In the first place, it is well known that a great extent of the spectrum totally invisible under ordinary circumstances can be recorded by means of photography. Thus, taking the length of spectrum which can be conveniently mapped by eye to extend from *h* (wave-length 4100) to near A (wave-length 7310), this map would be, on ÅNGSTRÖM's scale, 3·20 metres long. Taking about Q (wave-length 3177, MASCART) as the most refrangible limit of the spectrum conveniently workable by photography, we thus gain from this point to *h*, on the same scale, an additional length of nearly 1 metre.

Next with regard to the amount of detail obtained from photographs compared with that observable by eye. To illustrate the advantage of the present method, it will be instructive to compare a given region mapped by eye and by photography. The portion first selected has been mapped by ÅNGSTRÖM, by CORNU, and likewise in the course of the present work.

Solar Spectrum, Section 4000–4100.

Eye observation.	No. of lines.	Photographic record.	No. of lines.
"Spectre Normal"	32	CORNU's map	104
		Map constructed from RUTHERFURD's print of the solar spectrum	297
		Map constructed from negatives taken July, 1875 (including lines glimpsed merely)	333

In a region more easily visible than the above, the same superiority is exhibited by the photographic spectrum.

Solar Spectrum, Section 4200–4300.

Eye observation.	No. of lines.	Photographic record.	No. of lines.
"Spectre Normal"	94	Map constructed from RUTHERFURD's print of the solar spectrum.	275
		Map constructed from a negative taken July 29, 1875 .	412

Seeing the great advantages thus offered by photography, even in a part of the spectrum distinctly visible, I am persuaded that it will be necessary to re-map the whole length of spectrum capable of being photographed, before the conditions set forth at the commencement of this paper are fulfilled. Experiments made in the course of the present work show that, with a bromo-iodized collodion, it is possible to photograph as far as E in the green (wave-length 5269), with exposure of from two to three minutes. Neither can there be much doubt that, in a short time, we shall be in possession of methods enabling us to photograph any part of the spectrum with equal facility.

The importance of the photographic method will be still further enforced, if we consider that the maps of metallic spectra at present in existence, although constructed with the greatest skill, are necessarily incomplete, and are, moreover, not free from impurity lines. Before we can hope to arrive at any great generalisation in the theory of the spectrum, it is obvious that we must have pure spectra to deal with; and, as I have previously shown, the photographic method is the only one which enables such a purification to be effected.

V. PHOTOGRAPHIC PROCESS EMPLOYED.

The silver bath employed contains 40 grains of silver nitrate to the ounce of distilled water. It is made as neutral as possible.

Amongst many developers which were tried, I have found that used by Cornu to be best for these investigations, viz. :—

1 litre	Distilled water.
60 cubic centimetres . .	Saturated solution of ferrous sulphate.
30 ,, ,, . .	Glacial acetic acid.
30 ,, ,, . .	Alcohol.

In course of these researches I have used many collodions, but Blanchard's extra bromo-iodized is by far the best and most suitable for spectrum photography, as its power for imparting detail is greater than any other, and the granular appearance under magnification is less than that produced by others, although this defect is still great, and leaves much to be desired.

The emulsion process and also the dry plate processes have yet to be more thoroughly tested in connexion with this work, but at present the time of exposure required has proved a fatal objection.

Having obtained the negative, whether from the grating or a train of prisms, the next process is to produce the necessary enlargement. I have found no lens so well suited for these enlargements as Mr. Dallmeyer's rapid rectilinear. The working positive employed is a little below the scale of the map. The exposure required for transparencies is not so long as for a negative by about one-third. The intensifying solution should be passed over once, merely to secure the fine lines. The cyanide solution should be made rather weak for this work.

It is most important that both the negative and transparency should not be varnished, as the texture of the varnish will, when photographed, mar all fine detail.

VI. CONCLUSION.

In conclusion, I would remark that the accompanying map can only be regarded as provisional, seeing that when greater dispersion is employed, or a grating without the glass plate in front of it is available, much finer details will no doubt be revealed, and wave-lengths of all lines will be directly given.

With regard to the detail shown, I believe that the map as nearly represents the actual state of the solar spectrum at the epoch as can be expected with the photographic materials and dispersion at my disposal. There are some few lines which, when magnified, seem to show indications of being double, in some cases by a shading off on one side, in others by a trace of a central division. Such lines are, however, represented in the map as single, and the words "probably double" introduced opposite to them in the tables.

I may also mention that in other cases a solar line, although single under the highest magnifying power, has also been suspected to be double, because in my work on metallic spectra the supposed components have been found to be coincident with two lines in the spectra of two distinct metals, which lines just graze each other without actually coinciding.

The coincidence of the solar lines with those due to the vapours of the metals in this region I shall deal with in another paper.

In the annexed plate I have not only given the map, as reduced from the photographs in the manner described, but introduced a permanent enlargement of one of the photographs. It has not been possible to represent the intensities absolutely, on account of the varying tones of the absorption-lines themselves. The untouched photograph will allow of the detection of any errors of this nature.

I must express my obligation to the authorities of the School of Military Engineering, Chatham, for the permission they granted to have the enlargements made, and the reduced copy of the map photographed, there.

It is my duty and pleasure to record my deep obligations to my assistants, Messrs. MELDOLA, ORD, and STARLING for the care, patience, and skill they have successively shown in carrying on the various branches of the work. My thanks are also due to Corporals MURRAY and EWINGS, R.E., for their aid in enlarging the sketch maps and comparing them with the original negative.

In the map the lines have been fined down as much as possible to show the double lines, and the shading near H and K reduced to a minimum to show the finer lines in those regions.

TABLE I.—Fundamental lines used in the construction of Curves.

Section 3900–4000.

λ CORNU.	λ ÅNGSTRÖM.	λ Curve A from Photograph A.	λ Curve B from RUTHERFURD's print.	Error λ CORNU − λ A.	Error λ CORNU − λ B.	State in CORNU's Map.	State in ÅNGSTRÖM's Map.	State in Standard Photograph.	Intensity in Solar Spectrum 1 = darkest.	Remarks.
3897·0 (Fe.)	Absent.	3897·00	..	0	..	Single : winged	Absent	Single ..	1	
3898·4 (Fe.)	,,	3898·63	..	−·23	..	,, ,,	,,	,, ..	1	
3902·0 (Fe.)	,,	3902·10	..	−·1	..	,, ,,	,,	,, ..	1	
*3904·8 ..	,,	3904·77	..	+·03	..	,, ,,	,,	,, ..	1	
3909·4 ..	,,	3909·23	..	+·17	..	Single ?	,,	Double (?)	3, 2**	**Probably double. Identity with CORNU's line doubtful.
3913·4 ..	,,	3913·82	..	−·42	..	,, ...	,,	Double (?)	2, 2**	**Probably double.
3916·6 ..	,,	3916·50	..	+·1	..	,, ...	,,	Single ..	2	
3918·4 (Fe.)	,,	3918·72	..	−·32	..	,, ...	,,	,, ..	2	
3920·0 (Fe.)	,,	3920·00	..	0	..	,, ...	,,	,, (?)	1	Probably double.
*3922·1 (Fe.)	,,	3922·27	..	−·17	..	,, ...	,,	,, ..	1	
3927·2 (Fe.)	,,	3927·30	..	−·10	..	,, ...	,,	,, ..	1	
3929·8 (Fe.)	,,	3929·77	..	+·03	..	,, ...	,,	,, ..	1	
3935·2 ..	,,	3935·17	..	+·03	..	,, ...	,,	Double ..	3, 3	
3937·8 ..	,,	3937·72	..	+·08	..	,, ...	,,	Single .	2	
3940·0 ..	,,	3940·43	..	−·43	..	,, ...	,,	,, ..	2	
3941·8 ..	,,	3941·80	..	0	..	,, ...	,,	,, ..	2	
3943·1 ..	3942·70	3943·30	..	−·20	..	,, winged	Single	,, ..	1	
3946·9 ..	Absent	3947·00	..	−·10	..	,, ...	Absent	Triple ..	3, 3, 3	
3947·9 ..	,,	3947·85	..	+·05	..	,, ...	,,	Single (?)	2	Probably triple.
3950·0 ..	,,	3950·22	..	−·22	..	,, ...	,,	,, ..	2	
*3952·0 ..	3951·50	3951·72	..	+·28	..	,, ...	Single	Triple ..	2, 2, 2	
3955·0 ..	Absent	3954·50	..	+·5	..	,, ...	Absent	Single ..	2	
3955·8 (Fe.)	,,	3955·50	..	+·3	..	,, ...	,,	Triple ..	2, 2, 2	
3959·2 ..	,,	3959·48	..	−·28	..	,, ...	,,	Single ..	3	
3960·5 ..	3961·20	3960·50	..	0	..	,, winged	Single	,, ..	1	
3963·6 ..	Absent	3963·60	..	0	..	,, ...	Absent	Double ..	3, 3	
3965·0 ..	,,	3965·05	..	−·05	..	,, ...	,,	,, ..	3, 2	
3965·8 ..	,,	3965·80	..	0	..	,, ...	,,	,, ..	2, 2	
3968·7 ..	,,	3968·40	..	+·3	..	,, ...	,,	Single ..	1	
3970·4 ..	,,	3970·32	3970·45	+·08	−·05	,, ...	,,	,, ..	2	
3973·0 ..	,,	3973·00	3972·80	0	+·2	,, ...	,,	,, (?)	1	Probably double.
3975·5 ..	,,	3975·27	3975·33	+·23	+·17	,, ...	,,	Double (?)	3, 3**	**Probably double.
3978·9 ..	,,	3978·74	3979·00	+·16	−·1	,, ...	,,	,, ..	2, 4	
3981·0 ..	,,	3981·24	3981·20	−·24	−·2	,, ...	,,	,, (?)	2, 3**	**Probably double.
3983·7 ..	,,	3983·15	3983·40	+·55	+·30	,, ...	,,	Single ..	1	
*3986·1 ..	3986·0	3986·18	3986·36	−·08	−·26	Double	Single	Double ..	1, 1	
3989·0 ..	Absent	3989·12	3989·16	−·12	−·16	Single	Absent	Single ..	1	
3993·25 ..	,,	3993·60	3993·30	−·35	−·05	Single	,,	Double ..	2, 2	
3997·5 ..	3997·8	3997·72	3997·33	−·22	+·17	,, ...	Single	,, ..	1, 2	
3999·8 ..	Absent	3999·80	3999·80	0	0	,, ...	Absent	,, ..	2, 2	A line in ÅNGSTRÖM's Map at wave-length 4001·4 not capable of being identified.
4000·7 ..	,,	..	4001·24	..	−·54	,, ...	,,	Single ..	2	
4003·3 ..	,,	..	4003·40	..	−·1	,, ...	,,	,, ..	3	
*4004·4 (Fe.)	4004·7	..	4004·72	..	−·32	,, ...	Single	Double ..	1, 1	
4006·0 ..	Absent	..	4006·28	..	−·28	Double	Absent	,, ..	2, 2	
4007·4 ..	,,	..	4007·56	..	−·16	Single	,,	Single ..	4	
4008·6 ..	,,	..	4008·50	..	+·1	,, ...	,,	,, ..	2	
4009·40 ..	,,	..	4009·25	..	+·15	,, ...	,,	Double ..	4, 1	

* Lines marked thus are those measured absolutely by CORNU. Lines marked (Fe.) are iron lines, assigned to this metal by CORNU, which have been identified by a comparison photograph of Fe and solar spectrum.

N.B.—In the case of lines which the standard photograph resolves into groups of two or more, the centre is always taken for measurement. In the case of multiple lines, the intensities are placed in the same order as the lines are seen when looking at the map, *i.e.*, the more refrangible on the observer's left. The scale of intensities adopted is the same as that employed by THALÈN for the metallic spectra—1 being the darkest and 5 the lightest. In the overlapping portions of curves A and B the values given by B are adopted.

TABLE II.—Lines interpolated from Curves.
Section 3900–4000.

λ CORNU.	λ ÅNGSTRÖM.	λ Curve A.	λ Curve B from RUTHERFURD'S print.	Error λ CORNU − λ Curve.	State in CORNU'S Map.	State in ÅNGSTRÖM'S Map.	State in Standard Photograph.	Intensity in Solar Spectrum 1 = darkest.	Remarks.
Absent ..	Absent	3900·00	..	..	Absent	Absent	Double ..	3, 3	
3900·6 ..	,,	3900·60	..	0	Single	,,	Single ..	2	
Absent (?)	,,	3901·25	..	..	Absent ?	,,	,, ..	3	No distinct line in CORNU'S map.
3903·0 ..	,,	3903·16	..	−·16	Single ..	,,	,, ..	2	
3904·3 ..	,,	3904·08	..	+·22	,, ..	,,	,, ..	3	
3905·9 ..	,,	3905 80	..	+·10	,, ..	,,	,, ..	1	
3907·1 (?)..	,,	3907·17	..	−·07	,, ..	,,	,, ..	4	Identity with CORNU'S line doubtful.
3907·9 ..	,,	3908·10	..	−·20	,, ..	,,	Double ..	3, 4	
3909·9 (?)..	,,	3909·87	..	+·03	Double ?	,,	,, ..	3, 3	
3911·6 ..	,,	3911·30	..	+·30	Single .	,,	Triple ..	3, 3, 3	
3912·9 ..	,,	3912·80	..	+·10	,, ..	,,	Double ..	2, 2	
3915·2 ..	,,	3915·07	..	+·13	,, ..	,,	Quadruple	4, 3, 3, 3	
3917·8 ..	,,	3917·85	..	−·05	,, ..	,,	Single ? ..	2	Probably double. Represented in CORNU as beginning a broad band.
3921·4 ..	,,	3921·23	..	+·17	,, ..	,,	Triple ..	3, 3. 3	CORNU'S line in midst of shading.
3924·0 ..	,,	3923·85	..	+·15	,, ..	,,	Single ..	3	
3924·3 ..	,,	3924·42	..	−·12	,, ..	,,	,, ..	3	
3925·3 ..	,,	3925·28	..	+·02	,, ..	,,	,, ..	2	
3928·5 ..	,,	3928 62	..	−·12	,, ..	,,	Double ?..	3, 4**	**Probably double.
Absent ..	,,	3931·10	..	..	Absent	,,	Single ..	3	
Absent ..	,,	3936·72	..	..	,, ..	,,	,, ..	4	
Absent ..	,,	3939·50	..	..	,, ..	,,	,, ..	5	
Absent ..	,,	3944·61	..	..	,, ..	,,	,, ..	3	Centre of a group of four, represented in CORNU by a single line at 3944·2.
Absent ..	,,	3945·15	..	..	,, ..	,,	,, ..	5	
3946·2 (?)..	,,	3946·28	..	−·08	Single ..	,,	,, ..	3	Identity with CORNU'S line doubtful.
3948·9 ..	,,	3949·10	..	−·20	,, ..	,,	,, ..	3	
Absent ..	,,	3952·65	..	..	Absent	,,	,, ..	4	
Absent ..	,,	3957·60	..	..	,, ..	,,	,, ..	4	
3962·1 ..	,,	3962·20	..	−·10	Single ..	,,	,, ..	2	
3971·1 (?) .	,,	..	3971·40	−·30	,, ..	,,	,, ..	3	Identity with CORNU'S line doubtful.
3974·0 (?)..	,,	..	3974·13	−·13	,, ..	,,	,, ?..	2	Probably double. Identity with CORNU'S line doubtful.
3976·9 (?) .	,,	..	3977·18	−·28	,, ..	,,	,, ..	2	Identity with CORNU'S line doubtful.
3984·7 ..	,,	..	3984·80	−·10	,, ..	,,	,, ?..	2	Probably double.
3988·5 ..	,,	..	3988·50	0	,, ..	,,	,, ..	2	
3990·3 ..	,,	..	3990·49	−·19	,, ..	,,	,, ..	3	
3991·8 (?) .	,,	..	3992·25	−·45	,, ..	,,	,, ..	3	Identity with CORNU'S line doubtful.
3995·0 (?)..	,,	..	3994·63	+·37	,, ..	,,	,, ..	1	Identity with CORNU'S line doubtful.
3995·80 ..	,,	..	3995·25	+·55	,, ..	,,	,, ..	3	Identity with CORNU'S line doubtful.
3996·7 ..	,,	..	3996·75	−·05	,, ..	,,	,, ..	1	
Absent ..	,,	..	3998·35	..	Absent	,,	,, ..	3	

N.B.—In the case of multiple lines the same arrangement holds good as in the last table.

TABLE III.—Table of Wave Lengths 390,000 to 400,000 thousand millionths of millim.

Wave Length.	Intensity in Sun 1 = greatest.	Wave Length.	Intensity in Sun 1 = greatest.	Wave Length.	Intensity in Sun 1 = greatest.
390,000	1	391,518	3	393,435	5
390,023	4	391,555	3	393,475	3
390,048	3	391,570	3	393,495	3
390,105	3	391,605	3	393,628	3
390,135	2	391,648	2	393,672	4
390,162	4	391,675	5	393,718	3
390,180	4	391,700	5	393,745	2
390,220	4	391,725	5	393,885	4
390,240	1	391,754	2	393,920	5
390,270	3	391,773	2	393,948	5
390,290	5	391,815	5	393,975	2
390,335	2	391,835	2	394,026	3
390,373	5	391,865	5	394,050	3
390,423	3	391,882	5	394,080	3
390,441	4	391,915	5	394,136	5
390,478	4	391,945	1	394,149	2
390,500	1	391,978	3	394,178	5
390,535	4	391,991	3	394,223	3
390,585	2	392,008	2	394,250	3
390,600	1	392,025	3	394,273	3
390,622	3	392,050	3	394,300	1
390,650	5	392,080	3	394,368	3
390,673	5	392,123	5	394,381	3
390,692	4	392,165	5	394,422	3
390,712	5	392,180	5	394,440	3
390,732	4	392,200	1	394,481	4
390,765	5	392,250	5	394,515	5
390,785	5	392,265	5	394,568	5
390,810	3	392,295	5	394,600	3
390,825	4	392,338	4	394,650	3
390,875	5	392,368	3	394,665	3
390,900	3	392,438	3	394,680	3
390,922	2	392,488	3	394,720	3
390,968	3	392,523	2	394,731	5
390,985	3	392,555	4	394,776	2
391,010	3	392,568	4	394,815	3
391,025	3	392,615	5	394,885	3
391,040	5	392,665	4	394,938	3
391,075	5	392,700	1	395,012	2
391,102	3	392,735	3	395,038	5
391,115	3	392,755	3	395,055	5
391,128	3	392,762	3	395,070	5
391,158	3	392,785	3	395,092	4
391,223	3	392.830	3	395,110	5
391,258	4	392,845	4	395,130	5
391,275	2	392,883	4	395,160	2
391,290	2	392,900	3	395,190	2
391,335	4	392,950	1	395,210	2
391,360	2	393,000	4	395,248	4
391,375	2	393,023	3	395,278	4
391,400	5	393,100	3	395,295	5
391,425	5	393,165	3	395,338	4
391,451	4	393,221	4	395,365	4
391,480	4	393,270	1	395,385	5
391,492	3	393,325	3	395,423	2

TABLE III. continued.—Table of Wave Lengths.

Wave Length.	Intensity in Sun 1 = greatest.	Wave Length.	Intensity in Sun 1 = greatest.	Wave Length.	Intensity in Sun 1 = greatest.
395,450	5	397,148	4	398,598	1
395,472	5	397,155	4	398,635	1
395,498	3	397,200	4	398,678	5
395,530	3	397,238	4	398,695	3
395,548	3	397,275	1	398,728	5
395,568	3	397,305	5	398,742	5
395,600	2	397,338	3	398,768	5
395,668	3	397,361	2	398,800	4
395,700	3	397,382	2	398,848	2
395,722	2	397,430	3	398,922	1
395,748	5	397,448	4	398,972	2
395,775	4	397,478	4	398,985	5
395,820	5	397,495	4	399,045	3
395,850	5	397,535	3	399,065	4
395,875	5	397,555	1	399,100	3
395,920	3	397,578	3	399,155	3
395,935	5	397,625	5	399,172	5
396,028	3	397,685	2	399,215	2
396,055	1	397,722	5	399,238	3
396,115	3	397,741	3	399,250	5
396,130	3	397,760	3	399,274	5
396,172	4	397,785	3	399,288	5
396,182	3	397,810	5	399,325	2
396,215	2	397,830	5	399,348	2
396,242	5	397,868	2	399,375	2
396,268	3	397,880	4	399,398	3
396.330	3	397,915	4	399,465	1
396,362	3	397,975	4	399,498	5
396,450	3	398,000	4	399,520	3
396,508	2	398,023	4	399,533	4
396,525	2	398,038	4	399,570	3
396,550	2	398,065	5	399,610	5
396,571	2	398,083	2	399,625	5
396,662	4	398,105	3	399,648	2
396,741	1	398,150	3	399,665	3
396,832	2	398,168	3	399,688	1
396,865	5	398,215	3	399,728	1
396,882	5	398,240	3	399,750	2
396,911	4	398,273	5	399,778	5
396,925	3	398,320	1	399,798	2
396,948	3	398,345	3	399,848	3
396,976	5	398,360	3	399,875	5
397,000	5	398,385	3	399,920	5
397,035	2	398,423	3	399,958	2
397,078	5	398,465	2	399,977	2
397,120	3	398,550	2		

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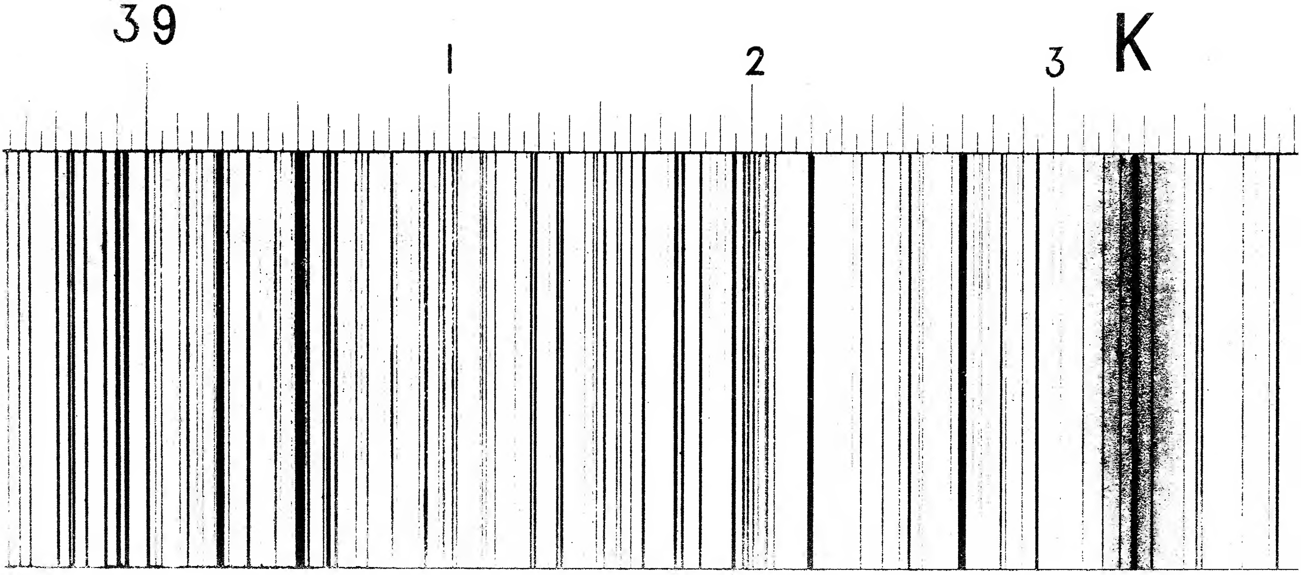

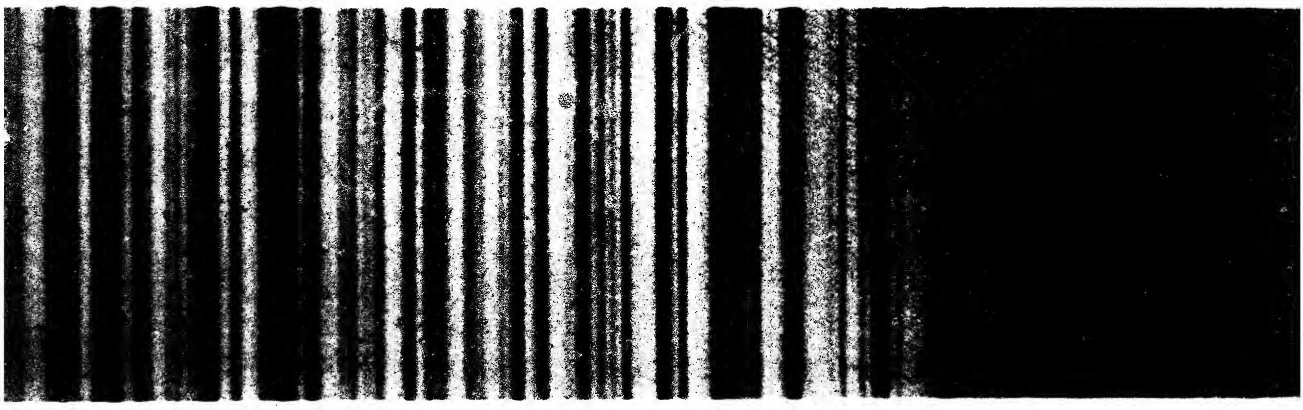

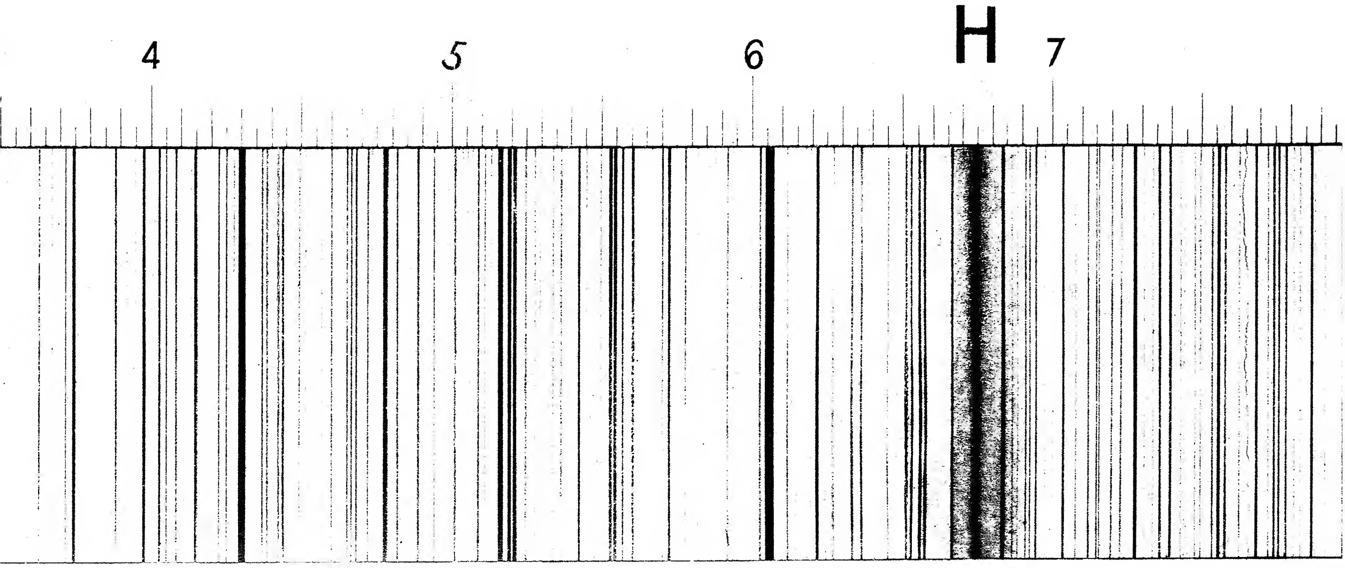
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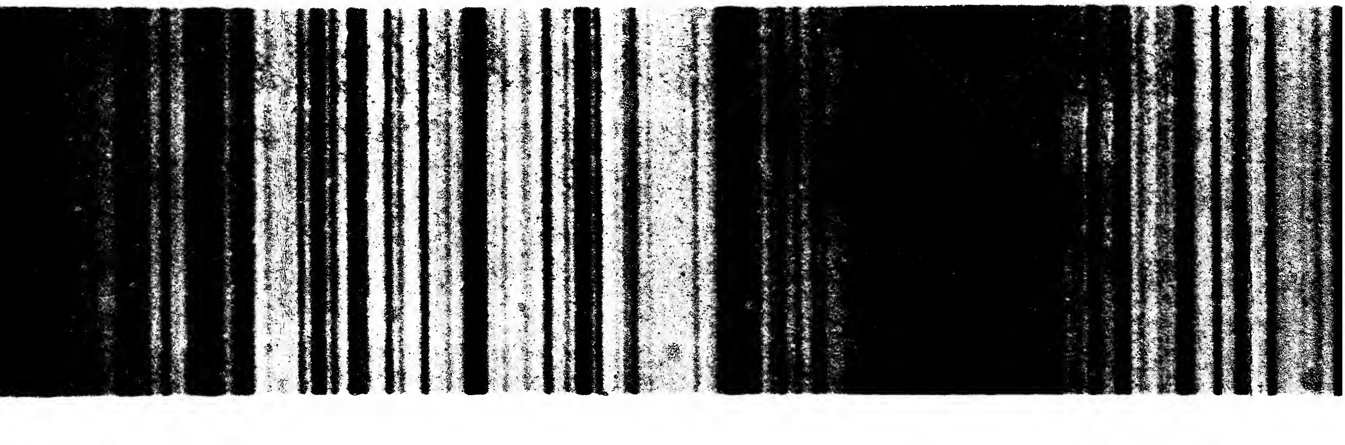

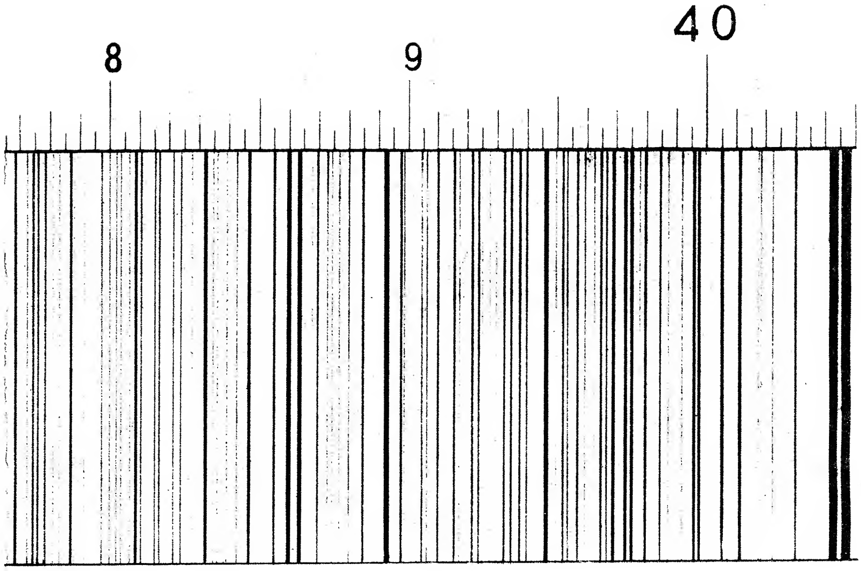

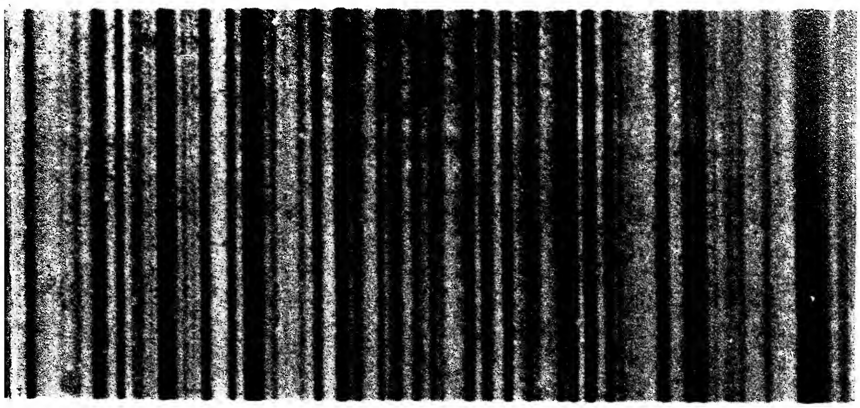

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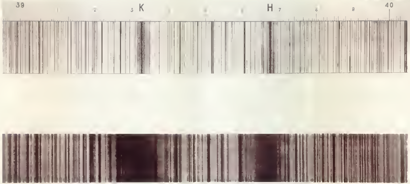
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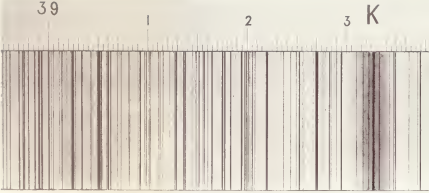

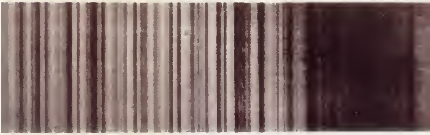

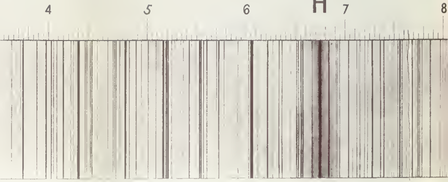
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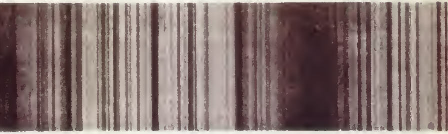

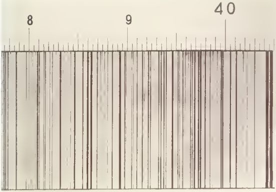

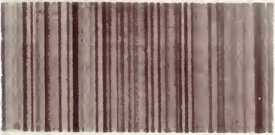

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